1997-98 El Niño effects on the pelagic ecosystem of the California current off Baja California, Mexico

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RESUMEN

Analizamos la respuesta del plancton a El Niño 1997-98 en la región sureña (26-32°N) de la Corriente de California, a partir de cuatro cruceros IMECOCAL. La clorofila *a* integrada en la vertical presentó un incremento moderado hacia el final del ENSO. No obstante la clorofila en Bahía Vizcaíno permaneció prácticamente constante (las medianas fueron superiores a 40 mg m^{-2} durante 1998). En contraste, la biomasa del zooplancton mostró una disminución desde Punta Baja (30°N) a Bahía Vizcaíno, pero no en otras áreas. La disminución de zooplancton en esta región fue debida principalmente a la baja abundancia de copépodos y eufáusidos, hacia el final del Niño. Valores de zooplancton relativamente altos en la región de Punta Eugenia (27.7°N) a San Ignacio (26.7°N), podrían ser explicados por la presencia de abundantes salpas. Una fuerte presencia de especies tropicales de copépodos fue observada durante el pico del Niño, siendo las más abundantes las oceánicas *Nannocalanus minor* y *Eucalanus subtenuis*. Las especies transicionales *Calanus pacificus, Pleuromamma borealis* y *Rhincalanus nasutus* tuvieron bajas abundancias.

PALABRAS CLAVE: El Niño, clorofila, zooplancton, copépodos, salpas, Corriente de California, IMECOCAL.

ABSTRACT

We analyze the plankton response to 1997-98 El Niño in the southern region (26-32°N) of the California Current, from four IMECOCAL cruises. Integrated chlorophyll *a* showed a moderate increase at the end of the ENSO, but chlorophyll in Vizcaino Bay remained fairly constant. The medians were higher than 40 mg m^{-2} through 1998. Zooplankton biomass showed a local decrease from Punta Baja (30°N) to Vizcaino Bay, but not in other areas. The zooplankton decrease was mainly due to the lower abundance of copepods and euphausiids at the end of El Niño. High concentration of zooplankton from Punta Eugenia (27.7°N) to San Ignacio (26.7°N), could be explained by the presence of abundant salps. A strong presence of tropical copepod species was observed during the peak of El Niño, most abundant being the oceanic *Nannocalanus minor* and *Eucalanus subtenuis*. Abundances of the transitional species *Calanus pacificus, Pleuromamma borealis* and *Rhincalanus nasutus* were low.

KEY WORDS: El Niño, chlorophyll, zooplankton, copepods, salps, California Current, IMECOCAL.

INTRODUCTION

Anomalous equatorial warming coupled to anomalies in the Western Pacific wind field is called El Niño/Southern Oscillation (ENSO) (Wyrtki, 1975; Philander, 1981). Physical effects along the coast include warming of the mixed layer, sea surface level rise, increase in geostrophic poleward flow, and deepening of the thermocline and of the nutricline (Huyer and Smith, 1985; Reinecker and Mooers, 1986). Atmosphere-ocean coupling is complex and different modes of ENSO development have been defined in the context of climate regime changes (Wang, 1995).

Biological ENSO effects are less documented than physical effects. Most of the available information for the California Current system (CCS) is on the event of 1982-83. In this event, primary productivity was reduced in the upwelling areas (Fiedler, 1984), apparently due to low nutrient input. The zooplankton biomass was also abated (Chelton *et al.*, 1982; McGowan, 1985), probably due to shortage in food supply. Insufficient plankton produces a chain reaction decline in upper trophic levels, but the decrease in biomass does not induce a similar effect among taxa. Low biovolumes observed during the 1958-59 El Niño in the California Current could be attributed mainly to gelatinous groups (Smith, 1985). Tropical and subtropical populations may be more abundant than usual, while subarctic populations decay. The replacement of anchovy by sardine in the Humboldt Current has been attributed to a low availability of phytoplankton used as food source by anchovy, and to the predatory activity of sardine on anchovy eggs (Arntz and Fahrbach, 1996).

The 1997-98 El Niño was the strongest since the event of 1982-83. From March 1997, the tropical Pacific experienced anomalous patterns of rain, cloudiness and atmospheric pressure. Winds were almost interrupted along the equator and the cyclonic activity of Northeast Pacific increased (CPC, 1997). In the CCS, evidences of El Niño were observed since July 1997. The coastal poleward current was strong, warm and saline. The thermocline was deeper and macrozooplankton extremely low (Lynn *et al.*, 1998).

Hurricane Nora struck the coast of Baja California in September 1997, with storms that affected the abalone banks of Natividad Island. The abalone harvest was the lowest since 1981-82. Kelp forests (*Macrocystis pyrifera*) used by these mollusks were completely destroyed by the hurricane. Two marine birds of Natividad Island (*Puffinus griseus* and *P. opisthomelas*) had their nesting seasons delayed several months (Keitt, 1998). In contrast, the Mexican spiny lobster (*Panulirus interruptus*) had a high settlement of larvae and juveniles in Tortugas Bay (Guzmán-Próo *et al.*, 2000), but the accelerated development of juveniles produced small reproductive females (Vega-Velázquez, 1999), probably because of high water temperatures during 1997.

Red sea urchin (*Strongylocentrotus franciscanus*) catches off Baja California decreased during the 1997-98 El Niño even more than in 1992-93 (INP, 2000). In contrast, small pelagic fishes, though negatively affected during 1997-98, were more strongly influenced during the event of 1992-93 (Hammann *et al.*, 1995; INP, 2000). Tuna fishery, mainly yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) had the maximum captures in 1997 (INP, 2000) in the Mexican Pacific. The variability in fisheries resources is closely related to the variability in plankton communities, their main food source. Therefore, we considered important to investigate the changes in plankton during the recent 1997-98 ENSO in waters off western Baja California.

METHODS

The selected area of the CCS in the present study comprised from Ensenada (32°N) to Laguna San Ignacio (26.7°N). Biological samples and oceanographic information were produced by the Program "Investigaciones Mexicanas de la Corriente de California", henceforth IMECOCAL. Four cruises were done between September 1997 and November 1998 (Table 1) on board of the R/V *Francisco de Ulloa*. Oceanographic stations in the IMECOCAL grid (Figure 1) correspond to the CALCOFI stations used in the past for the Baja California region by the Program "California Cooperative Oceanic Fisheries Investigations". During fall 1997, the area covered was from Punta Baja to Punta Abreojos. The rest of the cruises surveyed the total area.

Field methods

In every station CTD/rosette casts were done to 2000 m. Interpolated data of temperature, salinity, density and oxygen may be found in technical reports (García-C. *et al.*, 1997, 1998, 1999a,b). Water was collected with 5 L Niskin bottles from 0, 10, 20, 50, 100 y 150 m depths. During the first cruise only surface water samples were taken.

Water aliquots of 1-2 L from each depth were filtered at constant pressure to analyze pigment content, using GF/F filters. Also, aliquots of 250 ml from the surface sample were taken for taxonomic analyses of phytoplankton, preserved with a lugol solution and kept in the dark.

Zooplankton tows were done with a bongo net of 61 cm in diameter and 505 μm mesh. The net was hauled obliquely from 200 m to the surface at 2.5 knots. The volume of water filtered was measured with a flowmeter in front of the net. Samples were preserved with 4% formaline. Only one sample of the pair collected was used in this study.

Laboratory analysis

Analysis of chlorophyll a and pheopigments was done with a Turner fluorimeter, after extraction with 90% acetone during 24 h at 4°C (Holm-Hansen *et al.*, 1965; Venrick and Hayward, 1984). Samples used in phytoplankton identification and counting were settled 24 h before the analysis with an inverted microscope. Only 62 samples were analyzed (34 from Fall 97, 16 in winter 98 and 12 in summer 98).

Displacement zooplankton volume was measured following the method described by Smith and Richardson (1977), one-month after the last day of the cruise. Further identification and counting of superior zooplankton taxa (groups) and copepod species were done with a stereoscopic microscope. A fraction of the original sample was used (from 1/8 to 1/32 depending on the concentration of organisms in the sample). Zooplankton groups were counted in all samples, but copepod species only for the first two cruises.

Data analysis

Because data did not have a normal distribution, we used non-parametric statistics. The study area was divided

Table 1

IMECOCAL cruises, sampling period and number of oceanographic stations.

CRUISES	DATE	STATIONS
FALL 97	Sep 29 - Oct 6, 1997	39
WINTER 98	Jan 25 - Feb 11, 1998	69
SUMMER 98	Jul 15-30, 1998	65
FALL 98	Sep 28 - Nov 1, 1998	63

into five zones (Figure 1) and medians for biological variables were estimated. Night and daylight captures of zooplankton were compared with the Mann-Whitney test. Comparisons among cruises were done with the Kruskal-Wallis test for the median, and when significant differences were found, additional pair by pair comparisons were done with the Mann-Whitney test.

RESULTS

Plankton biomass

During fall 1997 surface chlorophyll a concentration was higher than 0.76 mg m^{-3} between Punta Baja and Vizcaino Bay, but in the remaining area almost all stations showed

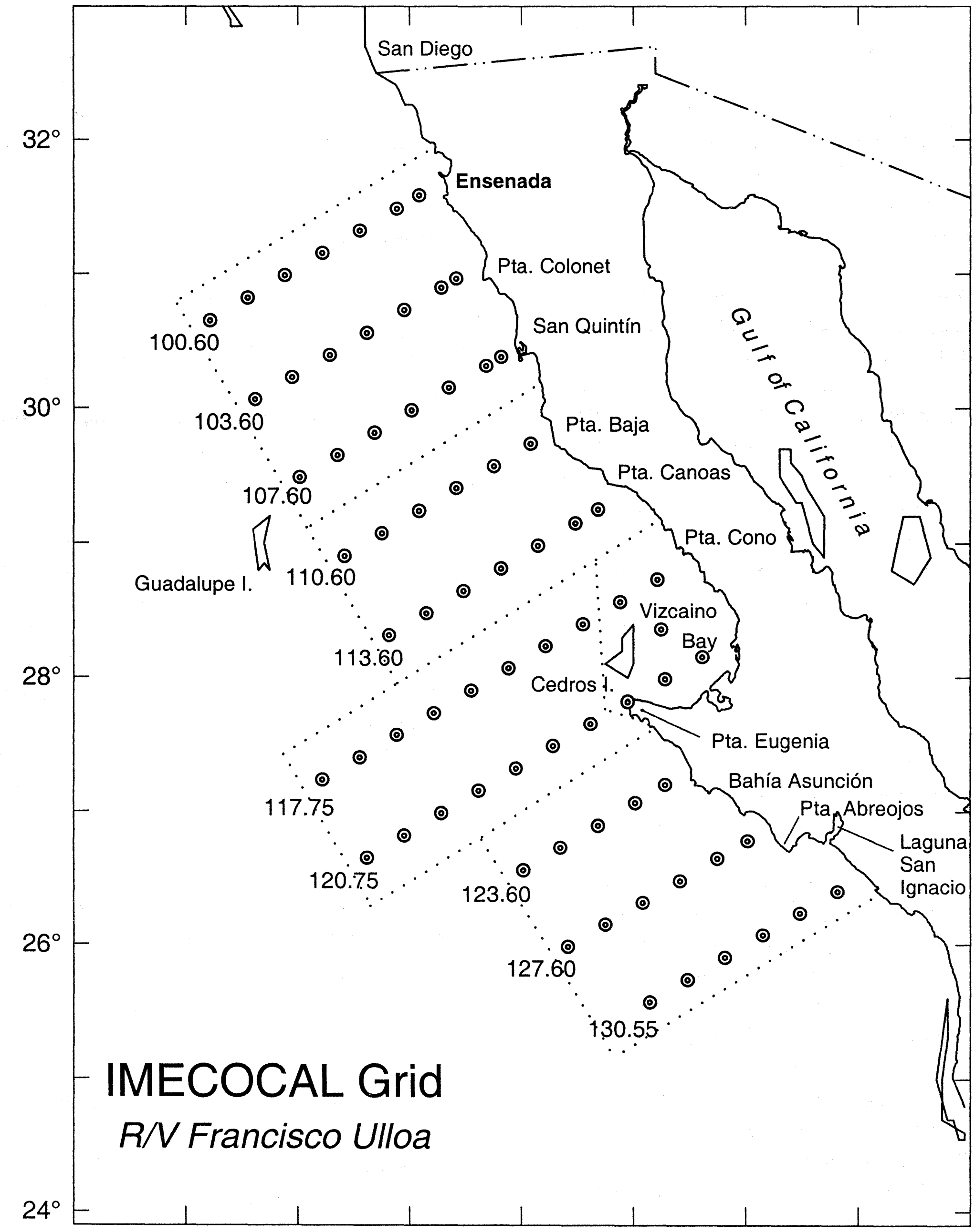

Fig. 1. Sampling stations during the IMECOCAL cruises. Dotted lines indicate zones used in the analysis of plankton biomass and abundance.

values lower than 0.25 mg m^{-3}. During the 1998 cruises, chlorophyll concentration integrated from 150 m to the surface showed medians of chlorophyll by areas in the range of 22 to 59 mg m^{-2}. High values were always found in Vizcaino Bay (Figure 2). The area between Punta Baja and Punta Canoas showed medians one third lower than those observed inside Vizcaino Bay, but were similar among periods. In other areas, winter 98 showed low values (medians lower than 30 mg m^{-2}), but chlorophyll increased further in the year (medians were between 31 to 50 mg m^{-2}).

Medians of zooplankton biomass were in the range of 5 to 28 ml m^{-2}. Low medians were always found in the northern sector (12, 14 and 8 ml m^{-2} in winter, summer and fall of 1998 respectively), while the areas of Punta Baja-Punta Canoas and Vizcaino Bay changed from rich zooplankton volumes during the ENSO peak to low thereafter (Figure 2). In the oceanic central area medians were lower than 20 ml m^{-2} from fall 97 to summer 98, increasing to 28 ml m^{-2} for fall 98. The most southern area was rich in zooplankton biomass during the four cruises. While phytoplankton biomass trended to increase in northern areas during the last 2 cruises, zooplankton decreased.

It should be borne in mind that sampling hour influences the amount of zooplankton captured, due to the tendency of many organisms to hide from predators during light hours in deeper strata, and swim up at night to feed near the sea surface. In this study we found that nighttime captures (median = 20 ml m^2) were significantly higher ($Z=-5.27$, $p<0.001$) than daytime captures (median = 11 ml m^2).

Phytoplankton composition

Phytoplankton groups from surface samples were thoroughly analyzed for fall 97 (34 samples), while winter 98 and summer 98 data were based on a lower number of samples (16 and 12 respectively), and more concentrated in the central and Vizcaino areas. Considering median abundance by areas, the highest variability was observed in centric diatoms, which peaked in fall 97 in the Punta Baja-Punta Canoas and Vizcaino regions (Figure 3), following a strong decrease in winter 1998. In the oceanic middle region, centric and pennate diatoms were more important during winter 98 compared to other periods. Despite the strong peak of centric diatoms observed in fall 97, naked dinoflagellates were the most consistent group through the region. The abundance of this group was relatively constant through the ENSO cycle, except in the area of Punta Baja-Punta Canoas, where a strong decrease occurred from fall 97 to winter 98.

In Vizcaino Bay, which is the shallowest area, the phytoplankton composition was rich in other groups (thecated dinoflagellates, cryptomones and nannoflagellates), apparently with low abundance in other areas. Nannoflagellates were important also in the oceanic central Baja California area throughout the period of study. Abundance of protozoans in our samples was low through the region.

Total phytoplankton abundance during fall 97 was highest in the north-northeast area, with medians close to 200 x 10^6 cells m^{-3}, twice the cell abundance found in the south-southwest area (Table 2). The reverse situation occurred in winter 98. It should be borne in mind that the described composition was based on surface samples. This means that abundance could be underestimated because phytoplankton biomass is not necessarily maximal at the surface. Moreover, particular phytoplankton groups could show maxima at particular depths, shifting the composition within different strata.

Zooplankton composition

Copepods were the most abundant consumers through the studied period in most of the areas (Figure 3). In Vizcaino Bay, they were found together with the euphausiids, in high abundance, during El Niño peak. The decrease of both groups was remarkable in summer and fall 98. Within the gelatinous herbivorous, appendicularians were also lightly higher in Vizcaino Bay, but in general were scarce in all the samples. Salps, other gelatinous herbivorous, had a different pattern, since their presence was important in the south and in the oceanic region, apart from their occurrence in Vizcaino Bay during summer 98 (Figure 3).

The most important groups of predators were chaetognaths and siphonophores. Variability in these groups follows the same pattern of their main prey, copepods and euphausiids (Figure 3). Other groups were found in the samples (decapods, amphipods, cladocerans, medusae, doliolids, etc.) but we show here only the seven most important.

Zooplankton total abundance was higher during the ENSO peak than the relaxation phase. Most of the medians per area were higher than 50 ind m^{-3} during fall 97 and winter 98, but under this amount during summer and fall 98 (Table 2).

Copepods and biogeographic affinities

Copepods were the most abundant zooplankton group during the ENSO cycle. A higher number of species were found in Fall 1997 (132) than in Winter 98 (118), despite that the number of samples analyzed in this last period was almost twice that of the first. However, only 32 of these species were found in at least 50% of the samples (in one or both cruises), which may be considered the dominant

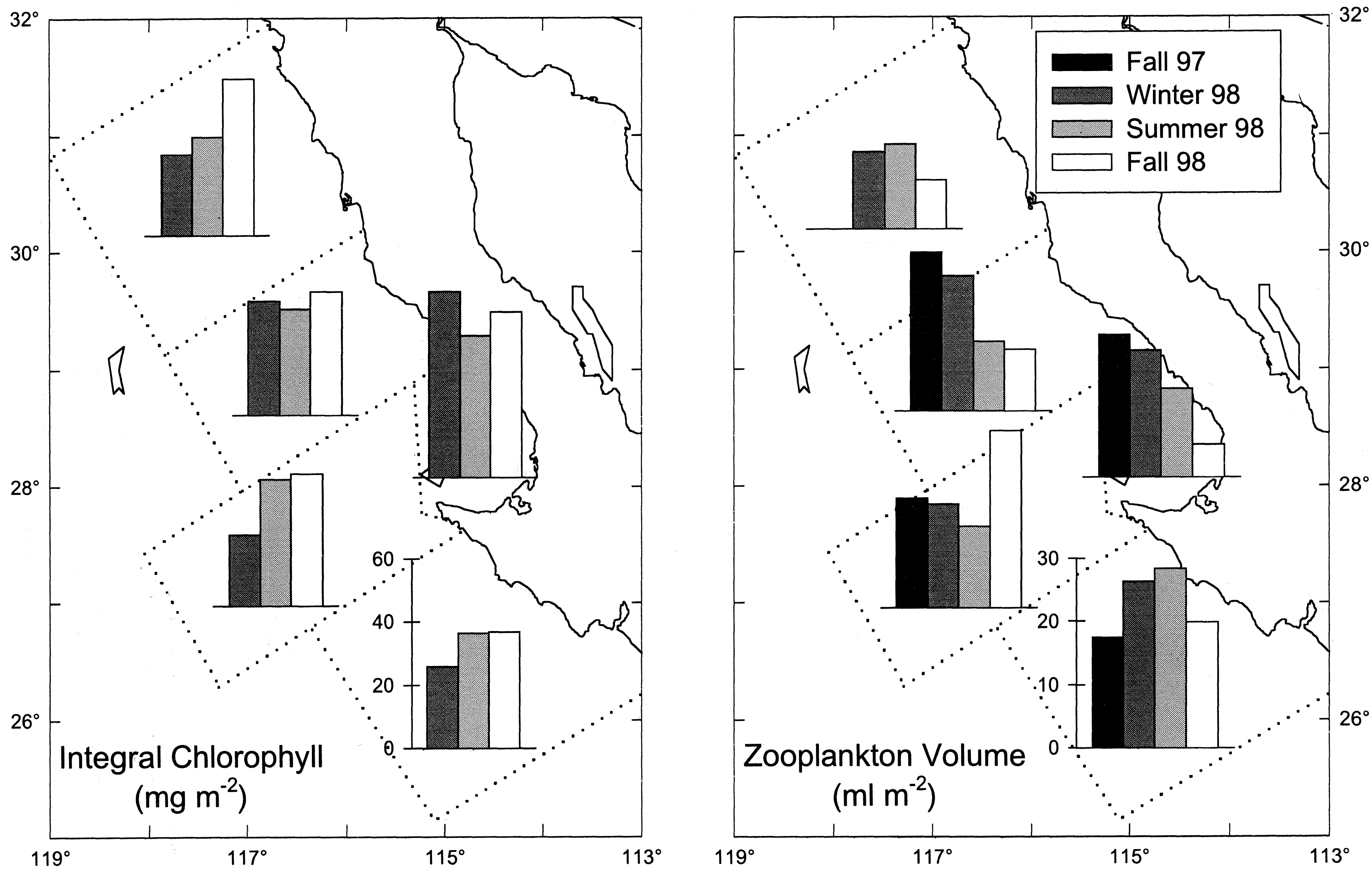

Fig. 2. Median biomass of phytoplankton and zooplankton during studied periods and areas.

Table 2

Medians of total phytoplankton (10^6 cells m^{-3}) and zooplankton (ind m^{-3}) during studied periods and areas. The number of analyzed samples is in parenthesis.

Areas	Period	Phytoplankton		Zooplankton	
Ensenada-San Quintín	WINTER 98	81	(3)	34	(21)
	SUMMER 98			20	(18)
	FALL 98			18	(16)
Punta Baja-Punta Canoas	FALL 97	218	(10)	58	(11)
	WINTER 98	62	(3)	64	(13)
	SUMMER 98			37	(13)
	FALL 98			20	(13)
Vizcaino Bay	FALL 97	212	(6)	96	(6)
	WINTER 98	161	(4)	119	(6)
	SUMMER 98	93	(1)	69	(6)
	FALL 98			48	(6)
Oceanic Central Baja	FALL 97	87	(12)	34	(11)
	WINTER 98	154	(5)	51	(13)
	SUMMER 98	71	(11)	34	(13)
	FALL 98			31	(15)
Punta Eugenia-San Ignacio	FALL 97	81	(6)	45	(9)
	WINTER 98	112	(1)	117	(16)
	SUMMER 98			53	(15)
	FALL 98			33	(11)

species during El Niño (Table 3). Within this assemblage there were three species typical of the CCS, *Calanus pacificus, Pleuromamma borealis* and *Rhincalanus nasutus* which are named transitional, because the CCS is defined as a transition zone between subarctic and equatorial waters (Brinton, 1962). The transitional group was present in relatively low abundance through the region in fall 97, increasing in winter 98 (Figure 4). However, the equatorial and tropical groups had higher relative abundance than the transitional one in almost all the zones during both cruises.

Equatorial species were more important in central Baja California and South of Punta Eugenia during both cruises, but a general increase through the region was evident from fall 97 to winter 98. Particularly, *Euclanus subtenuis* reached a median abundance of 5244 ind/1000 m^3, representing 40% of the accumulative total (all dominant species). Species in this group have a distribution restricted to the equatorial band, while those commonly named tropical have a distribution extended to warm-temperate waters. These last were also well represented during the ENSO peak, with *Nannocalanus minor* heading the list.

The only dominant species, with a more extended distribution, was *Paracalanus parvus*, which is common in subarctic and tropical waters. Though the relative abundance of *P. parvus* was low compared to other dominant species, it was consistent through the region during fall 97 (2-6% per zone). This species almost disappeared during winter 98, remaining restricted to the area of Punta Baja-Punta Canoas. No assignment of a biogeographic affinity was given to other dominant species such as *Oithona plumifera*, to five species of the Order Poecilostomatoida or to unidentified specimens of the genus *Clausocalanus*. These species maintained percentages between 8 to 14% in the different zones during fall 97 and between 3 to 7% during winter 98.

DISCUSSION

This study provides data of the plankton during El Niño 1997-98 in the southern third of the CCS. Lynn *et al.* (1998) described the physical development of this event along the California and Baja California regions, where the influence of El Niño conditions persisted from summer 1997 to summer 1998. In fall 1998 the ecosystem started the transition to cooler conditions, which developed through 1999 (Hayward *et al.* 1999). In the Baja California region a strong jet flowing northward near the coast was observed in September 1997. Positive anomalies of temperature and salinity were historic maxima (Lynn *et al.*, 1982). The anomalies are due in part to a long-term warming period related with changes in atmospheric circulation over the North Pacific (Ebbesmeyer *et al.*, 1991; Miller *et al.*, 1994; Trenberth and Hurrel, 1994; Roemmich and McGowan, 1995). However, it was clear that the most important part of this warming was caused by El Niño.

Following the evolution of El Niño, the expected plankton biomass increase after summer 1998, when the system returned to normal conditions, was observed for chlorophyll only in the area between Ensenada to San Quintin, but not in other areas off Baja California (Figure 2) and Southern California (Lynn *et al.*, 1998; Hayward *et al.*, 1999). The macrozooplankton lacked a coherent response in the two regions. In southern California the zooplankton volumes were at a historical minimum during El Niño peak (Lynn *et al.*, 1998; Hayward *et al.*, 1999), while in Baja California were close to the historical median (Lavaniegos *et al.*, 1998) from fall 97 to summer 1998. High volumes during El Niño were observed also in the Gulf of California, which remained high after the event (Sánchez-Velasco,

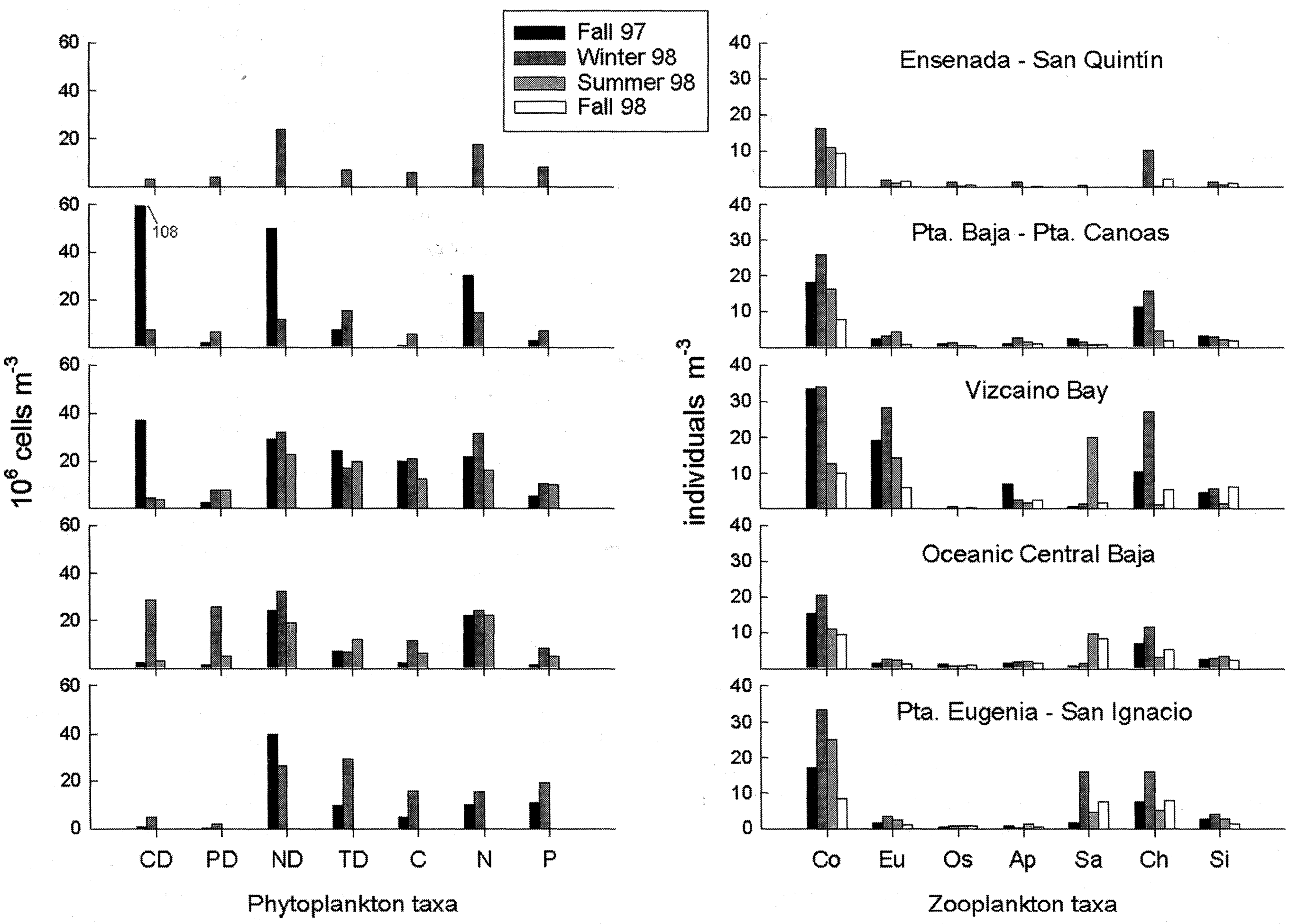

Fig. 3. Median abundance of phytoplankton (left panels) and zooplankton (right panels) groups during studied periods and areas. Centric Diatoms (CD), Pennate Diatoms (PD), Naked Dinoflagellates (ND), Thecated Dinoflagellates (TD), Cryptomones (C), Nannoflagellates (N), Protozoans (P), Copepods (Co), Euphausiids (Eu), Ostracods (Os), Appendicularians (Ap), Salps (Sa), Chaetognaths (Ch), and Siphonophores (Si).

Table 3

Dominant copepod species found during fall 97 and winter 98, biogeographic affinity and percentage of samples in which were present

SPECIES	FALL 97	WINTER 98
TRANSITIONAL GROUP		
Calanus pacificus	92	100
Pleuromamma borealis	38	53
Rhincalanus nasutus	72	85
EQUATORIAL GROUP		
Eucalanus attenuatus	85	97
Eucalanus subcrassus	38	71
Eucalanus subtenuis	82	100
Euchaeta indica	51	19
Euchaeta longicornis	46	79
Undinula darwini	95	90
TROPICAL GROUP		
Acartia danae	54	44
Centropages furcatus	54	12
Eucalanus pileatus	72	100
Euchaeta rimana	92	35
Euchaeta media	51	34
Haloptilus longicornis	49	66
Labidocera acutifrons	59	0
Nannocalanus minor	97	99
Neocalanus gracilis	15	69
Pleuromamma abdominalis	54	56
Pleuromamma gracilis	24	52
Pleuromamma piseki	26	66
Scolecithrix bradyi	49	71
Scolecithrix danae	92	84
Temora discaudata	77	93
Undinula vulgaris	92	6
SUBARCTIC-TROPICAL GROUP		
Paracalanus parvus	82	9
UNKNOWN AFFINITY		
Clausocalanus spp.	87	78
Copilia mirabilis	95	46
Corycaeus amazonicus	77	6
Corycaeus flaccus	51	31
Corycaeus speciosus	74	74
Oithona plumífera	87	63
Sapphirina nigromaculata	59	3

2000), contrasting with our observations off western Baja California, where a decrease in fall 1998 was evident. Local differences off Baja California were also evident. In the oceanic central area there was a direct, though modest, response by the zooplankton to the recovery of phytoplankton at the end of the studied period. In contrast, from Ensenada to Vizcaino Bay, zooplankton volumes were low independently of the increase in chlorophyll between Ensenada and San Quintin and the constant levels between Punta Baja and Vizcaino Bay. South of Punta Eugenia, zooplankton biomass remained fairly constant.

There were important changes in plankton structure during El Niño 1997-98. In fall 97 and winter 98, copepods and euphausiids were more abundant than in further cruises, particularly in Vizcaino Bay (Figure 3). This could explain high biovolumes in the area, in coincidence with high abundance of diatoms. The region from Punta Eugenia to San Ignacio had abundant salps through 1998, which could explain the high biomass; the contribution of salps in terms of volume is even more impressive, surpassing the crustacean contribution. The increase of salps could be related to the increment of chlorophyll because this herbivorous group has high filtration rates, and is less selective to diatoms.

The stable levels of the macrozooplankton biomass during El Niño peak in Baja California appear to be due also to an enrichment of tropical copepod species. Though the amount of chlorophyll was not extraordinary high, it could be sufficient to support important populations of copepods. Tropical species are smaller than the temperate ones and may compete better in conditions of a lower ration of food. Tropical and equatorial species (p.ex. *Nannocalanus minor* and *Eucalanus subtenuis*), carried into the region by the coastal poleward jet during El Niño and by central Pacific water, would compete for food better than the usual inhabitants of the CCS, *Calanus pacificus* and *Rhincalanus nasutus*. This interpretation must be taken with care, because the concentration of chlorophyll *per se* does not necessarily indicate production. Low phytoplankton biomass could also mean active grazing by zooplankton. In addition, transitional species could have been affected by other factors such as temperature and salinity. On the other hand, not all tropical species are small. The oceanic equatorial *Undinula darwini* and the tropical neritic *Undinula vulgaris* have sizes in the range of *Calanus* and were very abundant during fall 1997. A similar increase in biomass during El Niño due to a high input of tropical species was observed in fish assemblages in coastal waters off Jalisco (19°N), though some commercial species as the snapper *Lutjanus guttatus* decreased (Aguilar-Palomino *et al.*, 2001).

Is the high amount of tropical species in Baja California an indicator of the poleward carrying strength during the ENSO as well as other regions of the CCS? or is the Baja California region a more tropical province within the CCS, and therefore the response to the ENSO impact is different? There also could be in process a "tropicalization" of the Baja California region promoted by climate changes on a longer temporal scale. Future counting of copepods, when the ecosystem returns to more usual conditions, will cast some light about the possible recovery of the temperate species. In the mean time, the only signal we have is the record of a higher northward penetration of some equatorial species (*Undinula vulgaris, U. darwini, Eucalanus pileatus, E. subtenuis,* etc.), during the recent event of 1997-98 compared to El Niño 1958-59 (Fleminger, 1964, 1967).

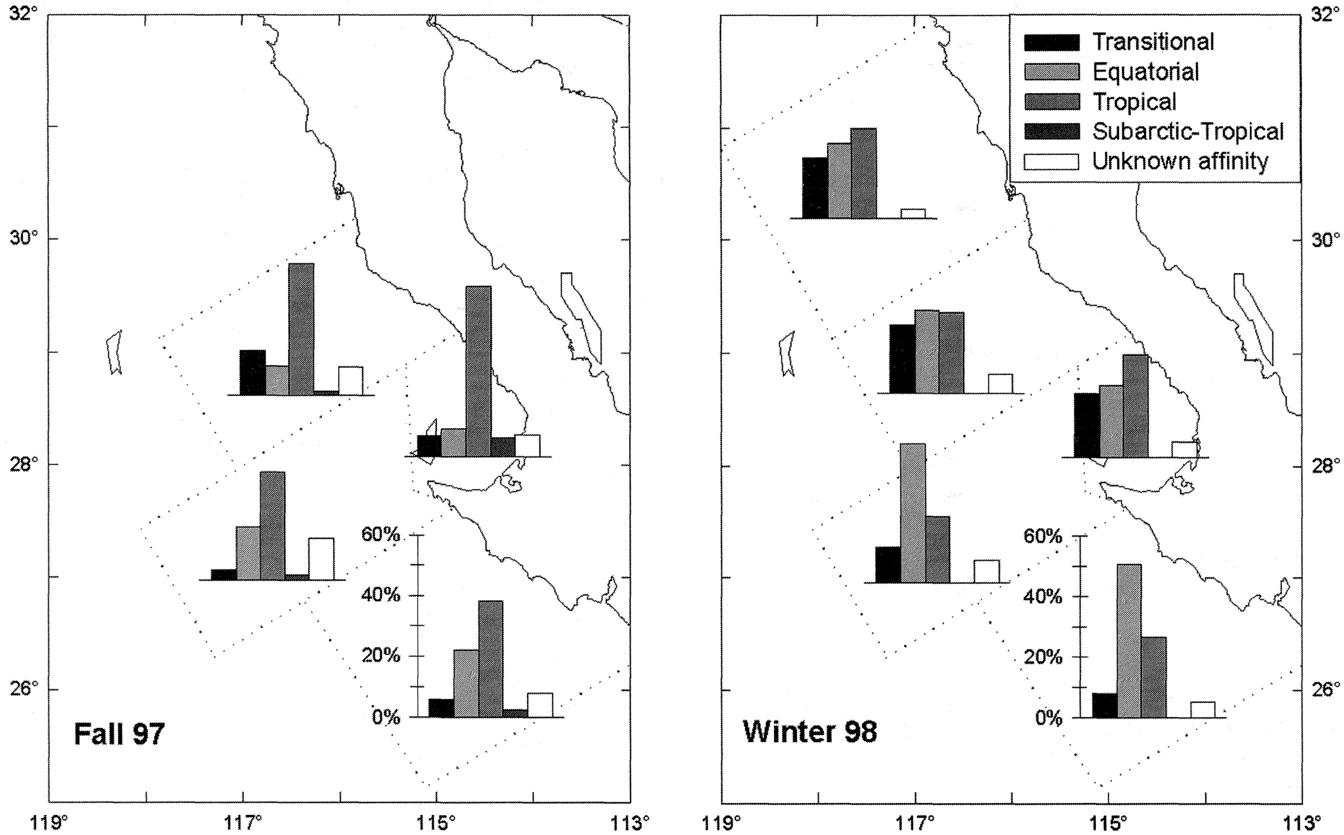

Fig. 4. Mean relative abundance by biogeographic groups of dominant copepod species by areas during Fall 97 and Winter 98.

Hypothetically the consequences of El Niño could be understood if the average structure of the planktonic community is known, similarly as the average physical structure of the ocean, but no time series of biological data for the CCS are available beyond the biomass. Therefore the climatic impacts can not be expressed as abundance anomalies or percentages of change. Even the records of species occurrence in the CCS (Fleminger 1964, 1967, 1973, 1975; Brodskii 1967, 1972; Palomares *et al.* 1998) do not always allow a precise assignation of biogeographic ranges. Fortunately, the collection of CALCOFI samples for the period 1951-84 for the Baja California region, should allow retrospective analysis of the zooplankton community.

Our results document the regional differences in response to El Niño 1997-98 within the CCS. The main finding was the unexpected stock of plankton biomass off Baja California, which was not negatively affected. It was necessary to analyze the community structure, which showed important changes in phyto and zooplankton taxa. Apparently, diatoms were restricted to certain areas, coinciding with high crustacean abundance. At the end of the ENSO cycle, crustacean groups decreased and salps increased. The response of the plankton to El Niño was more evident at the species level, as high densities of tropical copepod species were found during the peak of the event. Further studies on the community are necessary to understand the recovery of the ecosystem.

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